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RESULTS FROM AN EXPLORATORY STUDY OF AIRFRAME NOISE
ON A SMALL-SCALE MODEL OF A SUPERSONIC TRANSPORT CONCEPT

BY

JOHN S. PREISSER

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16. Abstract

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SUMMARY

An exploratory study of airframe noise on a small-scale model of a supersonic transport concept was made in the Aircraft Noise Reduction Laboratory at NASA Langley Research Center. The model was a 0.015-scale version without landing gear of Langley's Advanced Supersonic Technology configuration concept, AST-100. Noise measurements were made at positions corresponding to directly beneath the model and at 30° - sideline, for both cruise and the approach flaps configurations, at velocities up to 34 m/s. In general, results showed the cruise noise to be about 3 dB above the background flow noise and the approach noise to be about 11 dB above. Overall sound pressure levels and spectral shapes agreed with state of the art predictive techniques; however, the peak spectral frequency did not agree.

INTRODUCTION

Several years ago, airframe noise was recognized as a lower limit to the reduction of noise levels which could be achieved by further decreases in propulsion noise of commercial aircraft (ref. 1). At that time, indications were that airframe noise produced by a large subsonic aircraft during landing approach lay only about 10 EPNdB below

the FAR-36 certification levels. This result promoted research aimed at understanding and controlling the causes of airframe noise and predicting the levels. A critical assessment of the current state of the art in airframe noise can be found in reference 2.

In addition, for the past several years, the Langley Research Center has been actively engaged in work in advanced supersonic technology for potential application to future U. S. transport aircraft. Recently, the geometric characteristics of an advanced supersonic technology concept have been defined in a baseline-update study of earlier work, and given the designation, AST-100 (ref. 3). Low-speed aerodynamic characteristics of this configuration have been investigated using a 0.10 scale model and are reported in reference 4. Further low-speed tests using a 0.015 scale model with a simulated integrated propulsion system have also been performed. Unpublished data from these tests indicate that from a performance viewpoint Reynolds number effects in going from the larger to the smaller scale model were unimportant. The present noise study was undertaken using this smaller model with the proper vehicle attitude and flap settings that provided adequate low-speed performance for landing approach.

The purpose of the test was to explore the feasibility of performing airframe noise tests in the Aircraft Noise Reduction Laboratory at NASA Langley, and, if feasible, to obtain overall noise levels and spectra on a representative aircraft model. Airframe noise testing of both airfoils and complete models have been performed previously in other facilities, such as the NSRDC Quiet Flow Facility, the UTRC Acoustic Tunnel and the BBN Acoustic Wind Tunnel. A supersonic

transport model was chosen for the present investigation because of its timeliness and also because, being of very low aspect ratio, would provide a good check on the applicability of present day airframe noise prediction schemes to a new configuration. Most prediction schemes are semi-empirical and have been generated from a data base of chiefly full-scale high aspect ratio aircraft configurations.

TEST DESCRIPTION

Facility

The test was conducted at the NASA Langley Aircraft Noise Reduction Laboratory in the Anechoic Flow Facility. Figure 1 shows a photograph of the model mounted in the anechoic room. The room is 6.1 by 9.1 by 12.2 m high and has 0.84 m fiberglass wedges. A removable vinyl-covered metal grating provided access to the test stand and other parts of the room. The model was sting mounted through the top side and positioned in a nose-down attitude. The sting entered the model at a height of approximately 2.38 m above the floor. Airflow was provided by a 1.22 m vertical jet, which was driven by a centrifugal fan that was housed in another building to minimize extraneous background noise from entering the facility. Tests were run at flow speeds of 18.3, 24.4, 30.5, and 34.1 m/s.

Model

The model was a 0.015 scale AST-100. Detailed characteristics may be found in reference 3. Table 1 presents several geometric

parameters. A photograph of the underside of the model configured for landing-approach is shown in figure 2. Note that the model was not equipped with landing gear. Flap settings are given in table 2. Flap numbers in table 2 correspond to those found in figure 2. The flaps were generally simple wedge shapes attached to the wing by straight brackets. Engine nacelles were approximately represented by 2.5 cm diameter brass tubing with hemispherical plugs to prevent flow through. All data were taken at an angle of attack of 8°. Based on reference 4, this would result in a lift coefficient of about 0.6 for the landing approach configuration, and about 0.4 for cruise.

Instrumentation

The noise data were taken with three one-half inch condensor type microphones that were mounted on poles at a height of 2.38 m above the floor. A photograph of the model showing the microphone locations is presented in figure 3. Note that the height of the microphones corresponded to the vertical position where the model attached to the sting. Two of the microphones were in positions such that the model was directly overhead. The other microphone was at the sideline, at an angle of 30° from the overhead positions. The farthest overhead microphone and the sideline microphone were kept fixed at a radial distance, r, of 3.20 m; the nearest overhead microphone was generally kept at a distance of 1.32 m except for the landing-approach configuration where it was moved radially outward in fixed increments.

All data were high-pass filtered at 200 Hz, and analyzed on line to produce overall sound pressure levels (OASPL), one-third octave band spectra and narrowband spectra.

Test Environment

Figure 4 presents a sketch depicting the model in the free jet flow-field. The free jet is comprised of a low turbulent potential core surrounded by an annular shear layer of much higher turbulent levels. Unpublished data from flow-field surveys indicate the flow was uniform within the potential core of the free jet and turbulence levels were on the order of 0.3 percent of the mean flow. (Uniform, low-turbulent flow simulates flight through the atmosphere.)

It was desired to position the model high enough to minimize acoustic reflections from the jet nozzle, but low enough to keep the wing tips out of the turbulent shear layer. Once the model was in place, the vertical position of the microphones was fixed. All microphones were placed outside the flow field. The horizontal positions were such that two were in the far field, as mentioned previously. The position of the near-field microphone for most of the tests was determined by the point of closest approach to the model with no noticeable low frequency buffeting caused by the outer portion of the shear layer.

No corrections were applied to the measured data to account for the propagation of the airframe noise signal through the jet shear layer. It was anticipated that for low jet velocities and the measurement angles of interest, shear layer refraction and scattering effects would be very small.

RESULTS AND DISCUSSIONS

Overall Sound Pressure Levels

Overhead.- The change in overall sound pressure level with radial distance in a direction corresponding to the model being overhead is shown in figure 5 for various test configurations. Radial distance, r, has been normalized by wing span, b. The jet with sting can be considered as the background flow noise for these tests. (For this particular direction, the sting added little, if any, to the jet noise.) The background noise has been subtracted from the data. For the closest radial distance, the model in the clean configuration (cruise) is about 3 dB above the background, while the approach flaps noise is about 11 dB above. At the farthest radial distance, the differences are much less. For reference, the change of sound pressure level for a compact source in a free field environment (direct field) is also shown. Also, for reference, the corresponding scaled FAR-36 measuring point for approach (that is, $r/b = 2.69$ for a 3° steady glide angle at 1 nm) is indicated. Most of the data in this report will correspond to that measured at the closest radial distance ($r/b = 2.16$ or $r = 1.32$ m) since this position yielded the best signal-to-background noise ratio.

The variation of overall sound pressure level (OASPL) with velocity is presented in figure 6 for the overhead position at $r = 1.32$ m. Experimental model data from the present tests are presented in both the clean configuration (all flaps set at 0°) and the approach flaps configuration (flaps set as in table 2). Also shown

on the figure are the values predicted by Fink's simple airframe noise prediction equations (ref. 5), where the OASPL is given in units of decibels (dB):

aerodynamically clean;

$$\text{OASPL} = 50 \log\frac{U}{100} + 10 \log\frac{S}{r^2} + 100.3$$

landing configuration;

$$\text{OASPL} = 60 \log\frac{U}{100} + 10 \log\frac{S}{r^2} + 116.7$$

The levels and trends of the prediction agree reasonably well with the data for the clean configuration. Recall that the model did not have landing gear, so a comparison for the most critical landing configuration case could not be made. However, the model did have a flap system for landing, and these data were 8 dB above the clean data and several dB below what would be predicted if the model had landing gear as well.

There remains, of course, the question of scaling. Shearin et al (ref. 6), found that noise from a 0.03 scale model of a Boeing 747 agree to within $\pm$ 3 dB of the full-scale values (over the full-scale frequency range from 100 to 1500 Hz) for the case of both leading and trailing edge flaps deployed according to the relationships:

$$SPL_F = SPL_M + 10 \log (SF)^{-2}(U_F/U_M)^5(r_M/r_F)^2$$

and

$$f_F = (SF)f_M(U_F/U_M)$$

where the subscripts F and M designate the full-scale and model, respectively; SF is the scale factor, SPL is the one-third octave sound pressure level and f is the frequency. (It was also found

in reference 6 that the case with the landing gear deployed would not scale). Little, if any, other systematic experimental studies of scaling exist.

There is no solid evidence to expect this scaling law to apply to the present low aspect ratio, supersonic configuration. However, it is interesting to note that if the same scaling is applied to the case of a full-scale vehicle with approach flaps but without landing gear at $r = 113$ m and $U = 86.6$ m/s, OASPL is approximately 93 dB. This level is about 8 dB above the clean configuration prediction and 9 dB below the landing configuration prediction of Fink. Again, there was no model data with landing gear to assess the landing configuration prediction. Older prediction schemes, such as references 7 and 8, which use aspect ratio as a parameter raised to a large negative exponent, yield inordinately high values for airframe noise prediction of a low aspect ratio vehicle, like the AST-100. However, these prediction methods resulted from regression analyses of empirical data obtained from a small range of high aspect ratio aircraft, and hence may have become superceded in time.

It has been shown in figure 6 that the deployed flap system contributed a substantial increase in noise over the model in the clean configuration. Figure 7 presents the incremental increases obtained by successively deploying the inboard trailing edge flaps, the apex flaps, and the outboard trailing-edge flaps. It can be readily seen that the inboard set of flaps are, by far, the main contributor to the overall flap noise system increase.

Sideline.- The values of OASPL at 30° sideline in the far field ($r = 3.20$ m) were within $\pm$ 1.5 dB of the overhead measurement for both the clean and approach flap configurations. This result is insufficient to suggest much about directivity. However, it is not inconsistent with the monopole-like uniform sideline directivities measured by Fethney (ref. 9) and Lasagna and Putnam (ref. 10).

Spectra

Typical one-third octave band spectra are presented in figure 8 for the jet with sting (background noise), the clean configuration, and the approach flaps configuration. The data are generally broadband and peak at about 1,000 Hz.

For aircraft in the clean configuration, Healy (ref. 7) predicts the peak frequency to be

$$f_{max} = 1.3 \; U/t$$

where U is the velocity and t is a representative wing thickness.

For $U = 30.5$ m/s and $t = 1.53$ cm (max. thickness at mean aerodynamic chord), $f_{max} = 2{,}590$ Hz.

In contrast, Hayden (ref. 11) predicts trailing edge noise of an airfoil to have a peak frequency of;

$$f_{max} = 0.04 \; U/\delta$$

where δ is the boundary layer thickness at the airfoil trailing edge. For a turbulent boundary layer over a flat plate, $\delta = 0.37 \; c \; R_e^{-0.2}$, which is estimated to be about 1.0 cm for the present case. Hence, $f_{max} = 120$ Hz.

Other attempts at predicting peak spectral frequencies have employed parameters such as wake thickness (ref. 11), profile drag coefficient, and wing-tip vortex-core radius (ref. 12)) that may be difficult to estimate for new configurations. At the present, there does not appear to exist a simple, accurate prediction scheme for the frequency of the peak airframe noise of the present configuration.

Nevertheless, the spectral shape of the measured data agrees fairly well with the most commonly accepted prediction (ref. 7). Figure 9 presents nondimensional spectra for the clean and approach flaps configurations as compared to the prediction of Healy for a clean airframe. The frequency has been normalized to the peak frequency of each spectra (about 1,000 Hz from fig. 8). The data also suggest a relative increase in high frequency levels for the approach flaps case over that of the clean.

CONCLUDING REMARKS

A limited study of airframe noise on a 0.015 scale model (without landing gear) of Langley's Advanced Supersonic Technology configuration concept, AST-100 was made in the Anechoic Flow Facility of the Aircraft Noise Reduction Laboratory. Noise measurements were made at positions corresponding to directly beneath the model and at 30° sideline, for both cruise and the approach flaps configurations, at velocities

up to 34 m/s. Results showed the cruise noise to be about 3 dB above the background flow noise and the approach noise to be about 11 dB above, for the vehicle in the overhead position. Sideline noise was within $\pm$ 1.5 dB of the overhead noise for all cases. In addition, it was found that the simple airframe noise relationship of Fink agreed reasonably well with the experimental results for the cruise (clean) configuration. The cruise spectrum followed the nondimensionalized spectrum shape predicted by Healy. The peak frequency, however, was not predicted by any of the simpler, state of the art techniques. A preliminary look at scaling was attempted, but more work is required before model results from any arbitrary configuration can be used to predict full-scale values with confidence.

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TABLE 1. - Model Geometry

Wing area, S, m^2	0.23
Span, b, m	0.61
Aspect ratio, AR,	1.72
MAC, $\bar{c}$, m	0.51
Root chord, m	0.84
Tip chord, m	0.08
Thickness, t/c, % (approx.)	3
Leading edge sweep, deg.	
Inboard	74
Midspan	70
Outboard	60

TABLE 2. - Flap Settings

POSITION	NUMBER	SETTING
Inboard	1	40°
Inboard	3	40°
Inboard	5	40°
Outboard	6	5°
Outboard	7	45°
Apex	8	30°

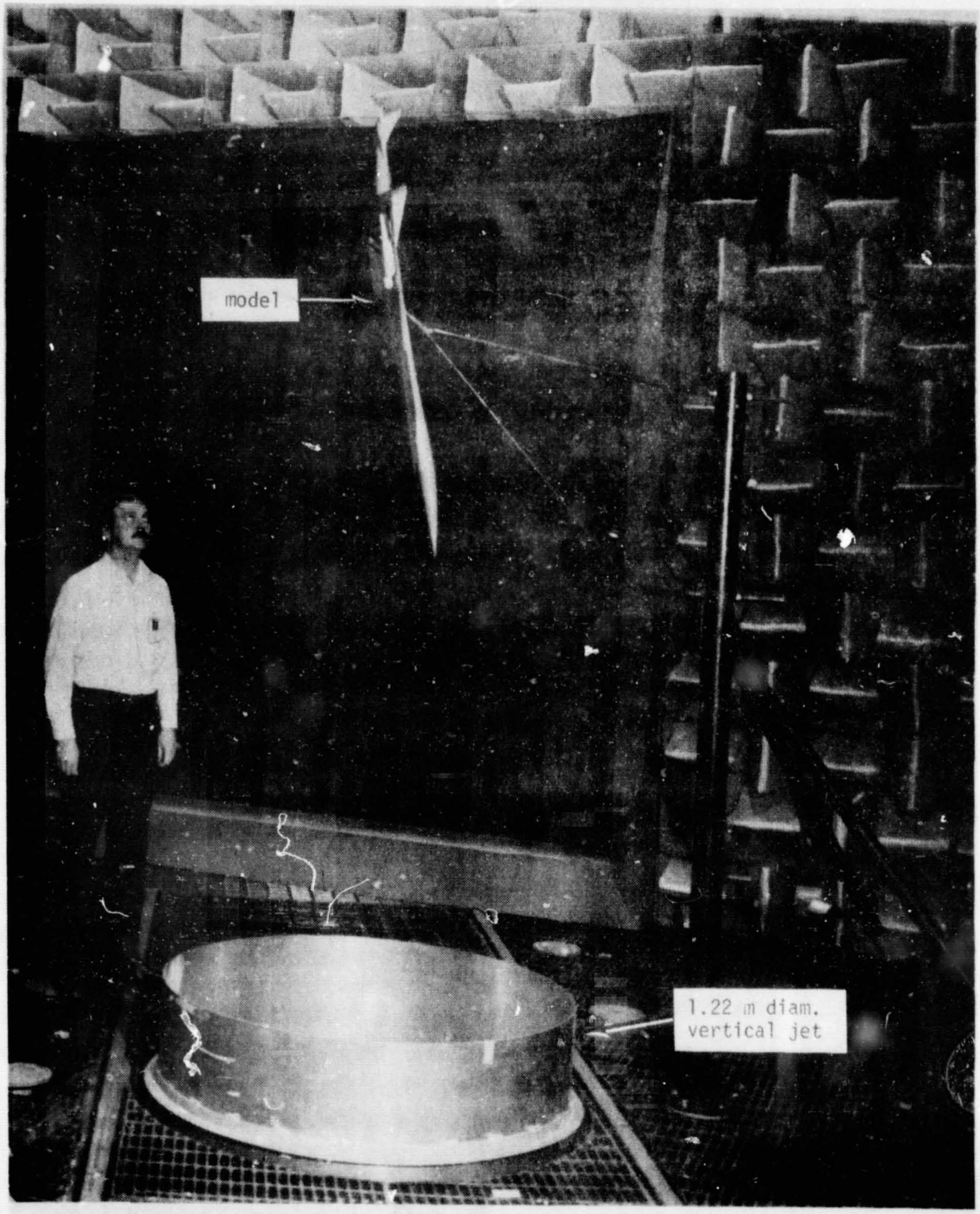

Figure 1. - Photograph of model in anechoic flow facility.

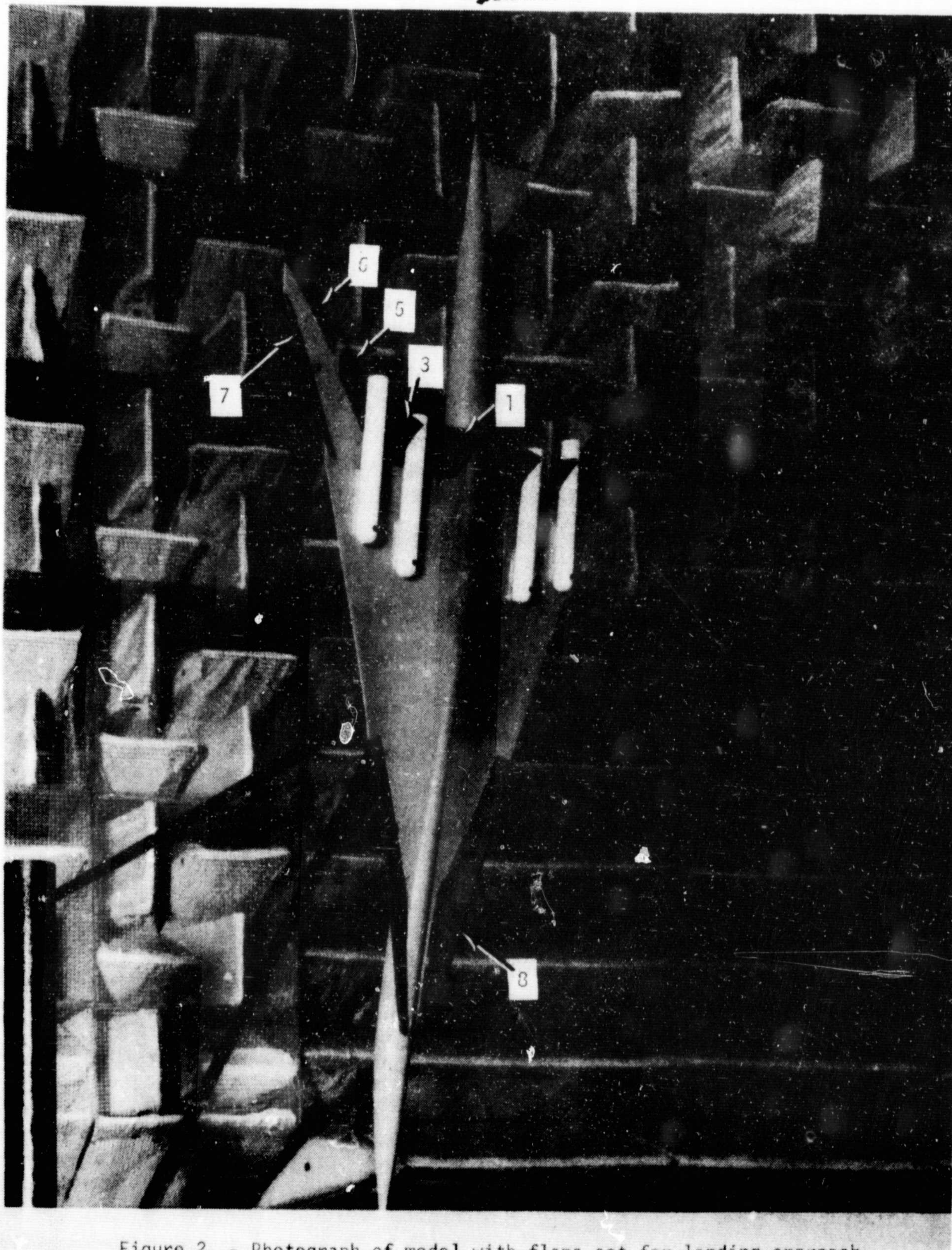

Figure 2. - Photograph of model with flaps set for landing approach.

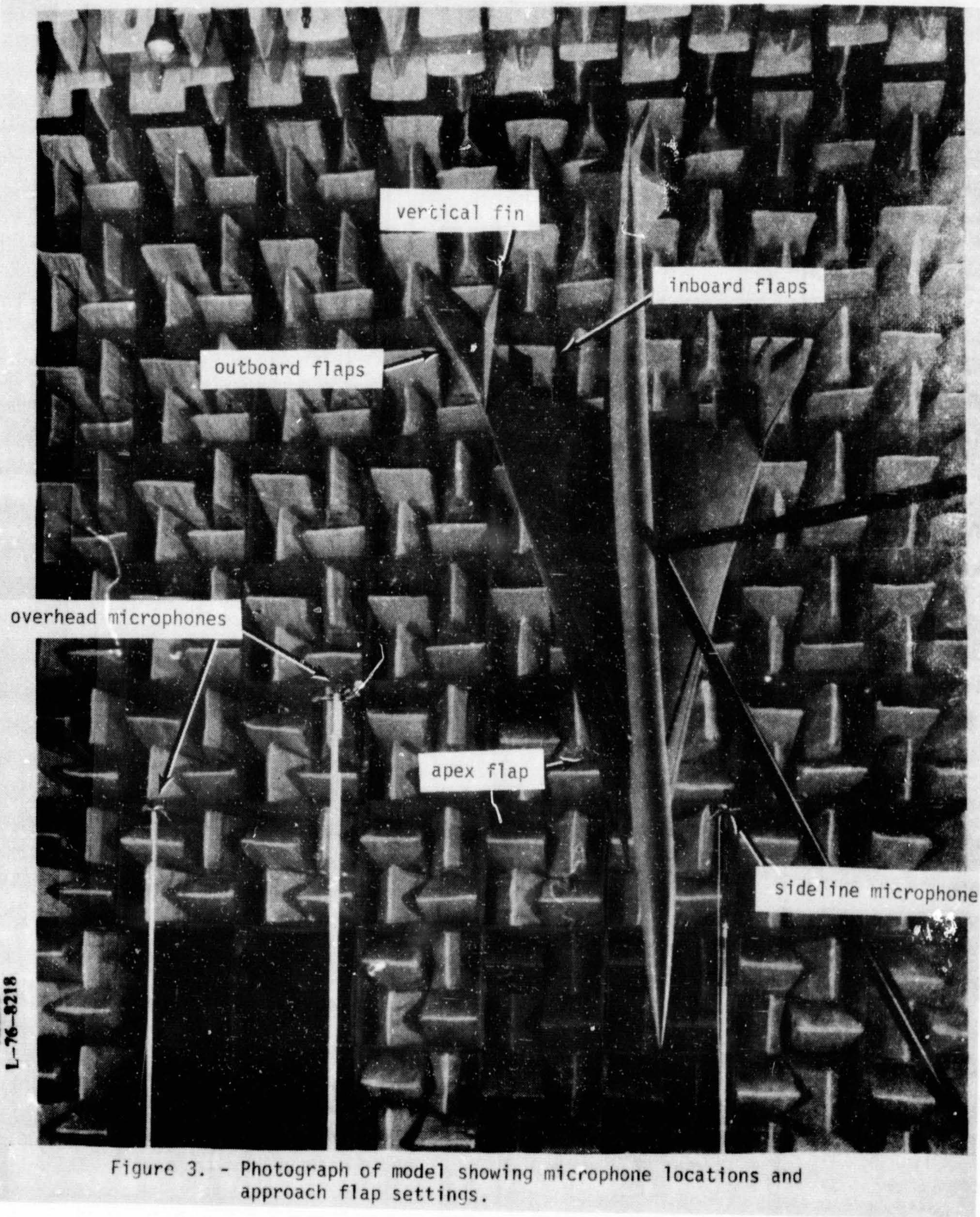

Figure 3. - Photograph of model showing microphone locations and approach flap settings.

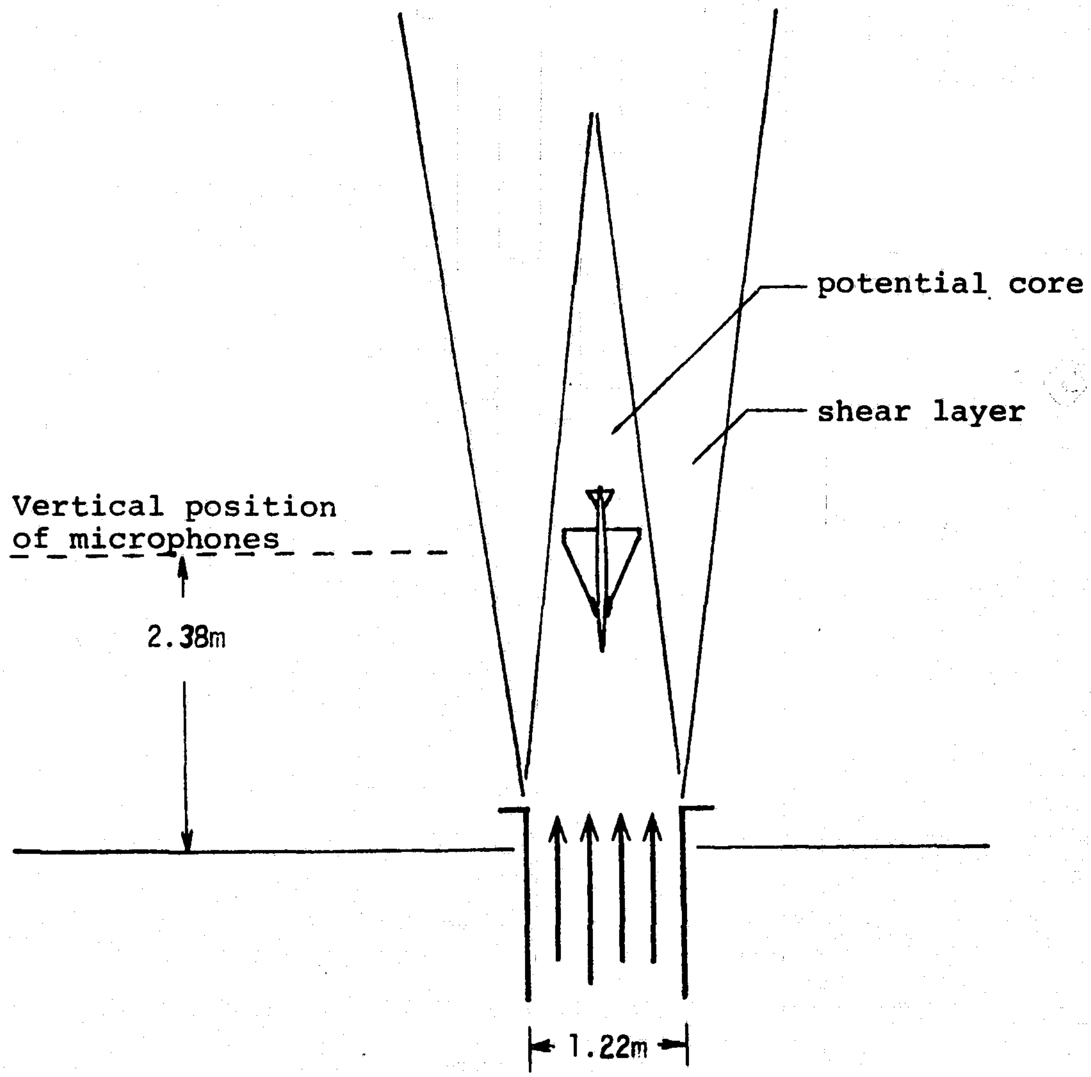

Figure 4. - Sketch depicting model in free-jet flowfield.

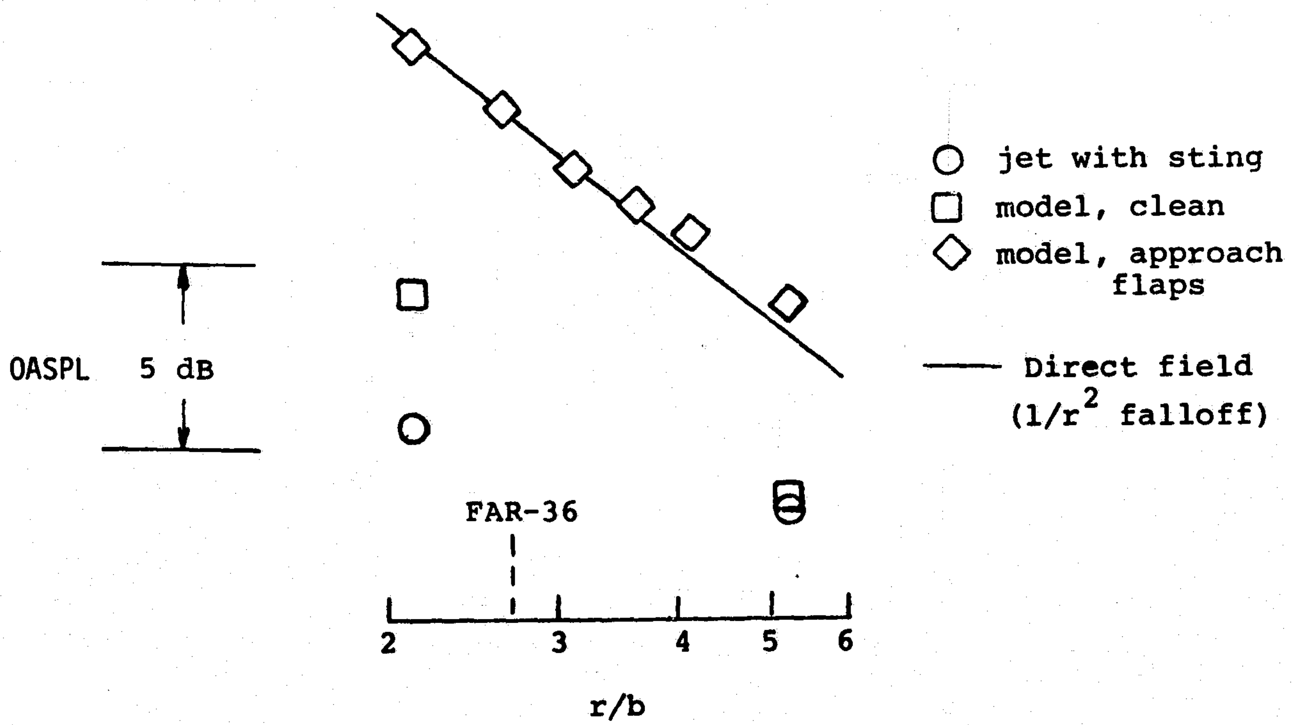

Figure 5. Change in overall sound pressure level with radial distance from model for various configurations. (U = 30.5 m/s.)

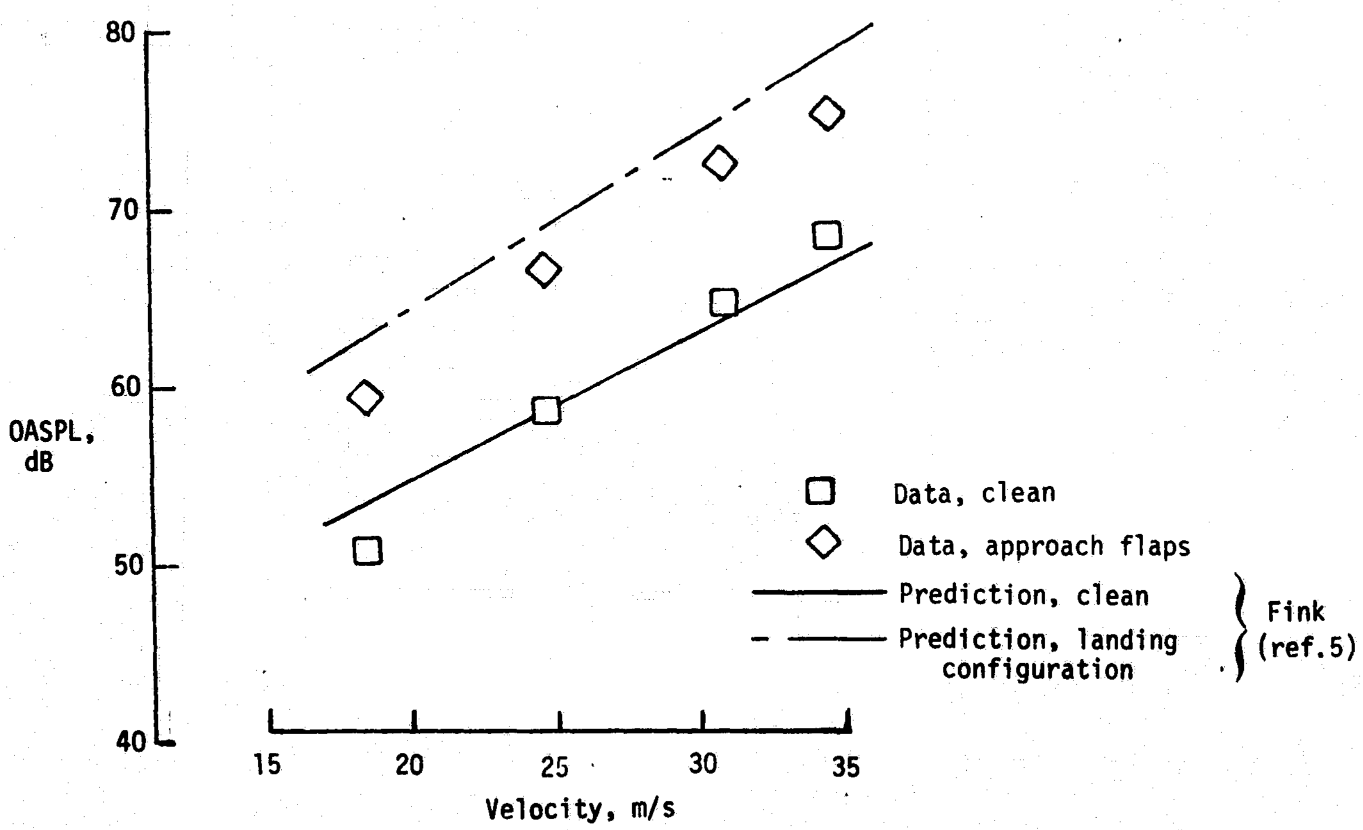

Figure 6. - Variation of OASPL with velocity for various configurations. (r = 1.32 m.)

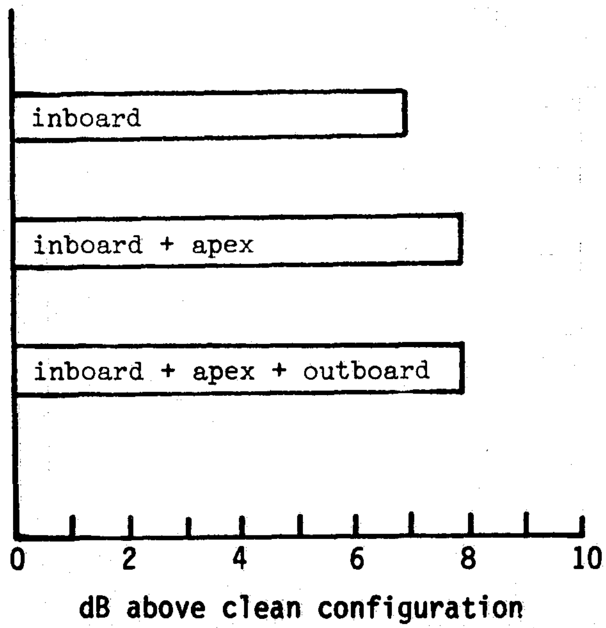

Figure 7. - Measured OASPL of various flaps deployed relative to clean configuration. (U = 30.5 m/s; r = 1.32 m.)

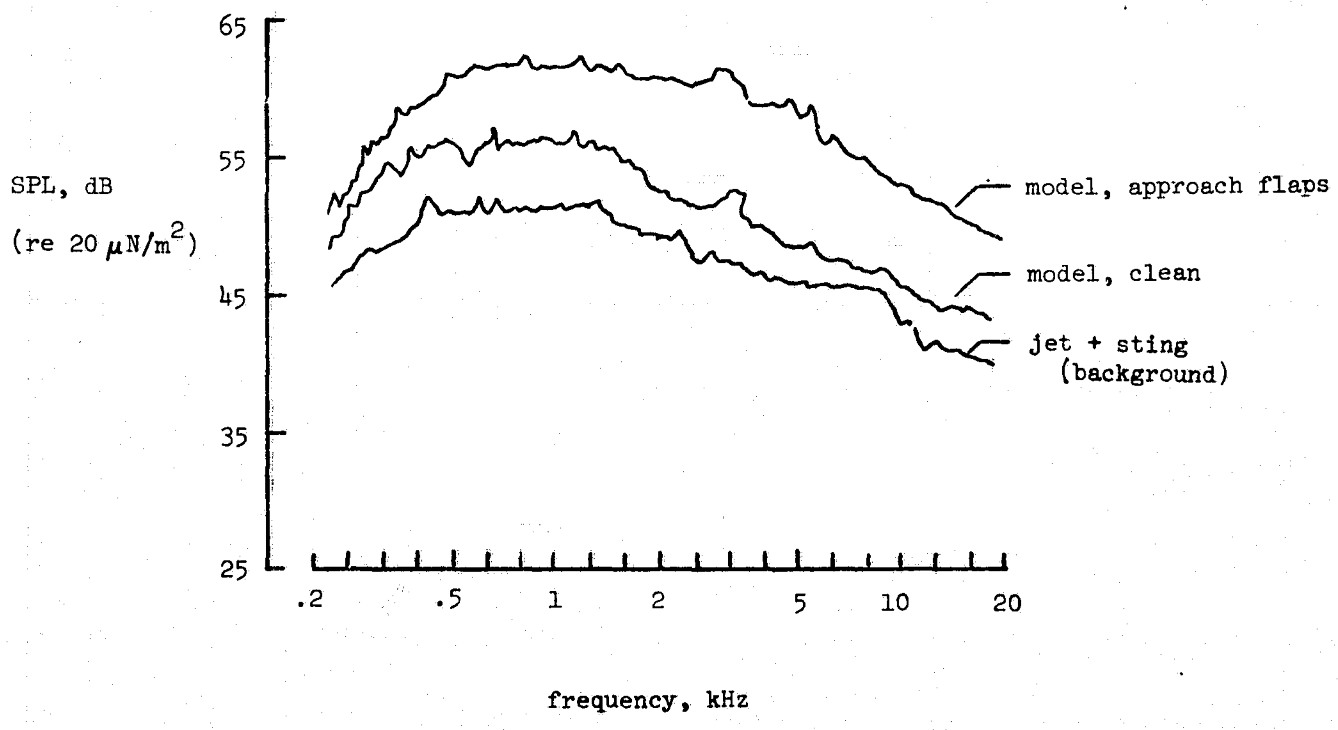

Figure 8. - One-third octave band spectra of various configurations
(U = 30.5 m/s; r = 1.32 m.)

NOTE: Model data has not been corrected for background noise.

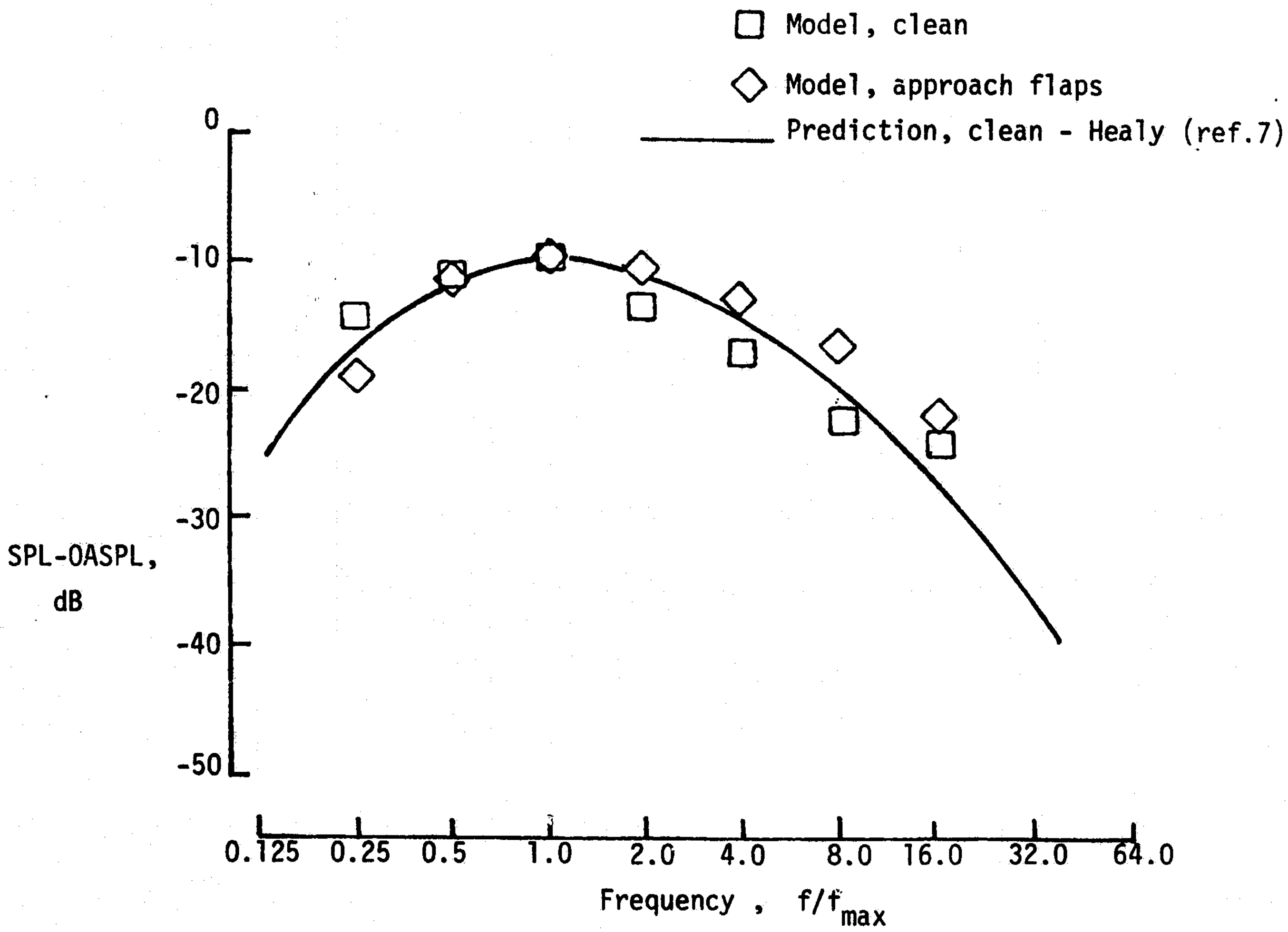

Figure 9. - Nondimensional spectra for various configurations